6b - Stream Simulation Design

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Stream Simulation Design Process

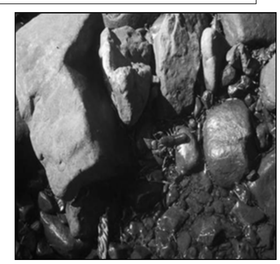
Assessment
Stream simulation feasibility
↓
Project alignment and profile
↓
Verify reference reach
↓
Bed shape and material
↓
Structure width, elevation, details
↓
Mobility / stability
↓
Design profile control →

- Project objective
- Simulate reference channel bed material
- Margins, banklines, forcing features
- Bed forms, shape

WHEN DESIGNING THE BED IT IS INTERGRAL TO THINK IN 3 DIMENSIONS.
HOW DOES THE DESIGN PROJECT PROFILE, ALIGNMENT, AND CROSS SECTION / BED CONFIGURATION INTERACT WITH THE EXISTING CHANNEL TERRAIN

Bed Design Objectives

- Simulate natural bed
  - control permeability (prevent water loss)
  - provides grade control
  - dissipates energy
  - creates complexity and hydraulic diversity
- Prevents excessive scour in structure

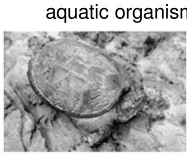
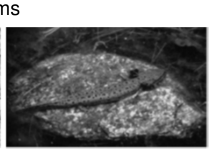


Scour is a natural part of the energy dissipation strategy of the stream. Inside the structure scour will occur and the design must consider the scour depth when determining structure invert elevation (footing & structure, structure type or the need for defensive measures

Roughness = AOP

These elements help control channel gradient and provide enough **flow resistance** (roughness) to maintain the diverse range of water depths and velocities needed for fish and other aquatic species passage.

Outside of the structure these features create unique micro habitat features used by various life stages and aquatic organisms


Roughness Elements

Roughness is Cumulative and Caused By:

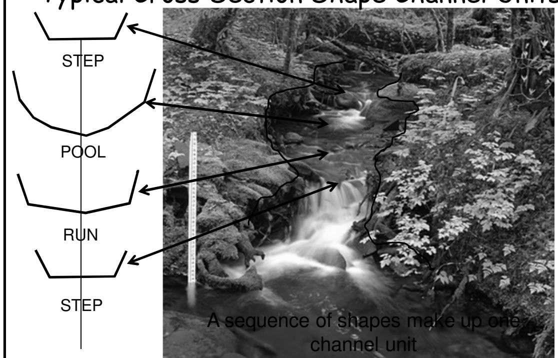
- Channel shape.
- Bed material particle-size distribution.
- Bedforms (fixed or mobile) & Key Features that constrict the channel and are major roughness elements.
- Bank vegetation
- Bank irregularities.
- Channel bends - length of structure

THIS IS WHAT IS SIMULATED IN THE DESIGN

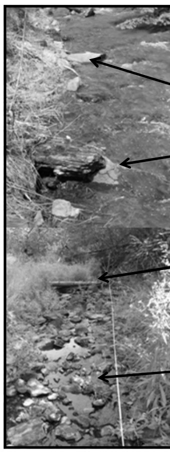
Stream Simulation Bed Elements (building blocks of a complex channel)

- **VARIABLE** CHANNEL WIDTH AND CROSS-SECTION SHAPES. Cross sections of pools, steps, tail crest and riffle vary in shape and widths. Each cross section type can vary in size also .
- ONE OR MORE PARTICLE SIZE DISTRIBUTION (GRADATION) RANGES TO:
  - simulate the natural streambed (design bed mix)
  - construct structure elements (riffles, pool tail crests)
  - and/or protect structure (riprap slope protection or deeply buried immobile beds for footing protection)
- INVIDIUAL ROCKS OR CLUSTERS OF ROCKS (KEY PIECES)
  - construct stable banks
  - create structural elements (step-pool, ribs, or similar features)
  - scattered roughness elements (also form habitat rocks)

High Gradient Channels (Step Pool) Typical Cross Section Shape Channel Units



Roughness Elements



Solitary boulder near channel margin

10" Dia. Log juts 2ft into channel with 14" Dia. boulder

7" Dia. Log overhangs bed and extends from bank to CL channel into channel

Boulder clusters and isolated boulders throughout channel bed
10" to 14" Dia.

Isolated boulder clusters

From site assessment data determine:

- Roughness type
- Dimensions
- Spacing
- Position within channel
- Area of coverage
- Number of pieces per element and unit area

Variability of Bed Design Elements

- NOTHING IN NATURE IS EVEN / AVERAGE OR SYMMETRIC
- The reference reach has a range of spacing of critical bed elements. Use the spatial range to mesh our design with the stable bed features we will tie to at the end of the project profile.
- Average spacing is OK for simplicity but need tolerances so placement isn't uniform and doesn't increase costs.
- Critical structures (typically steps) should have defined location with tighter tolerances than general roughness elements

Typical Natural Grade Control & Energy Dissipating Features

	Boulder Clusters	step & pools	steps	scattered Boulders (Colluvium)	riffle	gravel bars	large wood	frequent & persistent small wood
Cascade	X	X	X	X			X	
Step Pool	X	X	X	X			X	
Plane Bed	X		X	X			X	X
Pool Riffle - high stability				X	X	X	X	X
Pool Riffle - low stability				X	X	X	X	X
Sand Bed / Dune Ripple						X	X	X



Features based on Montgomery and Buffington THE TYPE OF BED STRUCTURES BUILT IS CHANNEL TYPE DRIVEN!!!!!

Channel Types:

- Cascade channels
- Step-pool channels
  - Forced channels
- Plane-bed channels
- Pool-riffle channels
- Dune-ripple channels

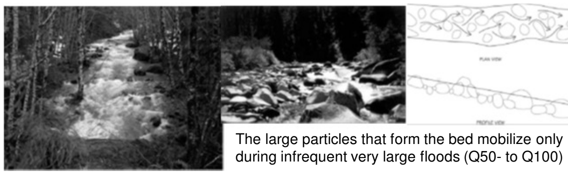
General trend:
Increasing slope
=
Decreasing mobility and greater stability

Special Cases:

- Bedrock channels with veneers of sediments
- Channels of cohesive bed material

BEDFORMS BUILT OUT OF CONTEXT WITH THE CHANNEL TYPE ARE UNSUSTAINABLE LONG TERM

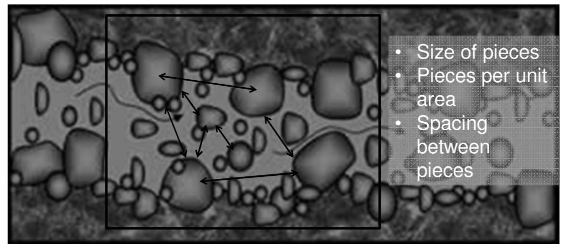
Cascade Reach



The large particles that form the bed mobilize only during infrequent very large floods (Q50- to Q100)

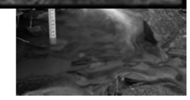
- Steep slopes of about 10- to 30-percent slope
- Frequently confined by valley walls. No real floodplains
- Tumbling, turbulent flow over and around individual disorganized cobbles and boulders scattered or clustered throughout.
- Small pools do not span the entire channel width

Cascade Reach Bed Design

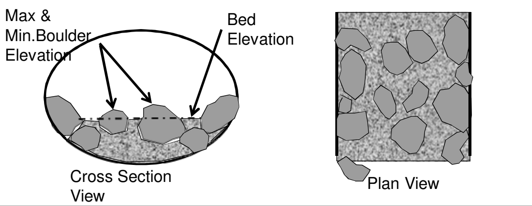


control.

•Machine placement for good particle interlocking.



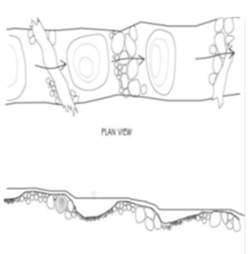
Example of Cascade Bed Design



Design based on ref. reach roughness, key piece spacing and distribution:
•Banks – place alternating 1.5 and 2.5ft diameter boulders embedded 50% and in direct contact with each.
•Key cascade pieces – alternate 1 – 2 ft diameter and 2 - 1.5 ft diameter boulders spaced every 4.5 ft. Spec min & max gap between boulders
•Use a CAD program to make sure it fits inside the structure!

Cascade post construction & near bank full

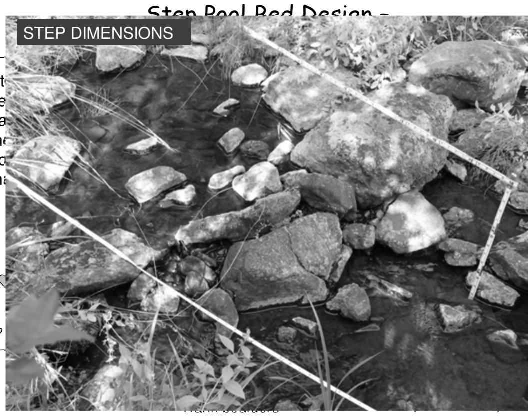
Step-pool Reach
Boulder Creek, Colorado



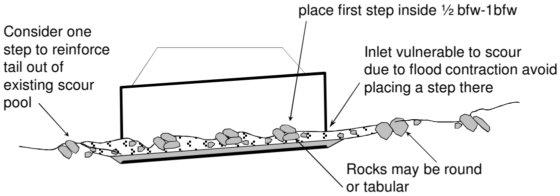
Step-pool reaches

- Large rocks and wood form channel-spanning steps
  - Usually spaced at about one to four channel widths.
  - Energy is efficiently dissipated as flow plunges into pools
- Typical average channel slopes range from 3 to 10 percent slope
- Bed structure is more stable than a less organized streambed.
- Steps mobilize and reform during large floods (Q30-Q80) (may be more frequent when bedrock is relatively shallow)
- Design steps for stability at Q100
- Finer sediment moves over the steps during moderate high flows. (as it does in all channels at various flows)

Step Pool Bed Design –

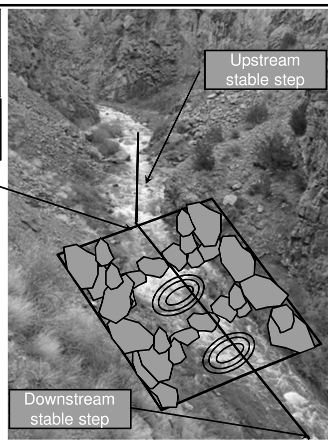


Other Specific Step Location Considerations



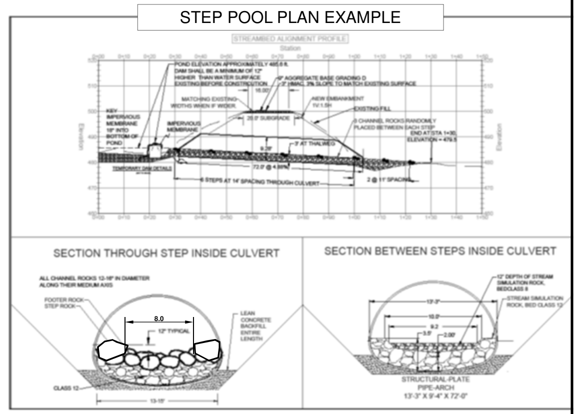
Step pool channels

Step Pool Layout Tying into Channel



- Mesh constructed bedforms based on reference reach but has to fit within the stream tie points
- If structure to stream geometry is skewed a pool will form. This needs to be considered when placing additional bedform.

STEP POOL PLAN EXAMPLE



Step Pool Example Ripton, Vermont

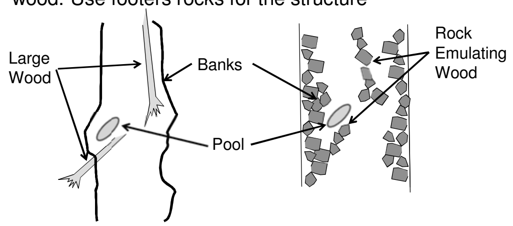
Wood Forced Channel

Mag Creek, Mt Hood NF, Oregon

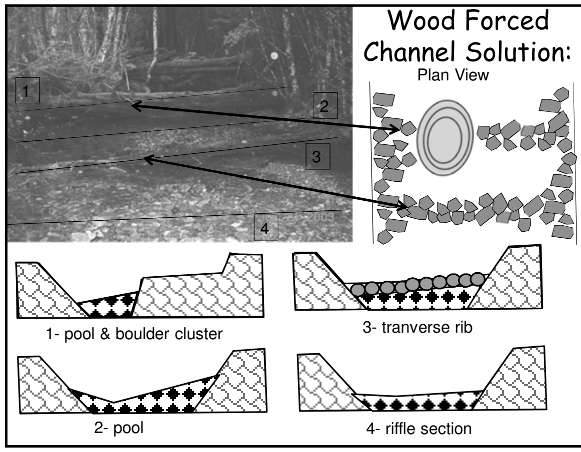
McGlynn Ck, Siuslaw NF, Oregon

Wood Forced Channel Design

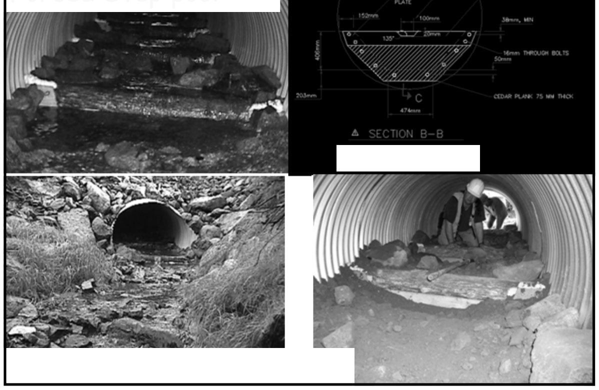
- Review spatial distribution, size, and orientation of wood in reference reach
- **Size rock for stability**. Most wood is persistent for long periods of time and we can't grow trees in the culvert
- Construct rock steps / vanes, boulder clusters to emulate wood. Use footers rocks for the structure



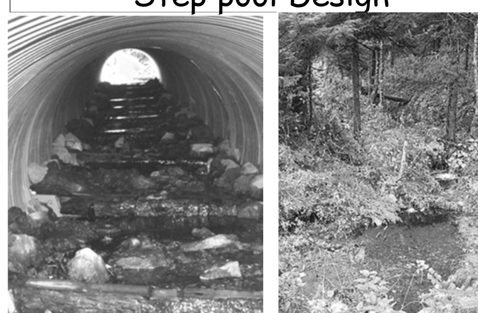
Wood Forced Channel Solution:



Experimental Wood Forced Step pool



Experimental Wood Forced Step pool Design



Wood forced step pool system w/ 0.7 - 1ft step heights, fine grain alluvial fan system, D84 = 1", At this site step height dictated by Biologist not the Stream!

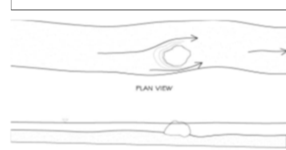
Summary so far:
High Gradient and Wood Forced Channels:

Channel Types:

Cascade - Step-pool - Wood forced channels

- All key pieces (steps, cascade boulders, etc) and banks are designed to be stable at Q100
- Channel cross sections vary depending on what part of the 'CHANNEL UNIT" they represent
- Energy dissipation is key! Design channel has to have equivalent roughness, pool dimensions and frequency as the reference reach.
- Need dense gradation to reduce permeability

Plane-bed Channels



Massachusetts

Southeast Alaska

Plane-bed Channel

- Long stretches of relatively featureless bed without organized bedforms.
- Moderate gradients (1 – 3%) in relatively straight channels,
- Usually with armored gravel-cobble beds.
- Bed mobilization occurs at flows near bankfull.
- Infrequent grade controls typically:
  - Colluvium / Key pieces in clusters or high frequency
  - Small Steps without pools, Large or small wood, ocassional poorly organized transverse ribs
- In the East often associated with historic land management impacts (channel straightening, logging, etc.)

Plane Bed Design

Design armored stream simulation bed using:
- Stream simulation material and
- Scattered boulders for roughness in bed and along structure edges

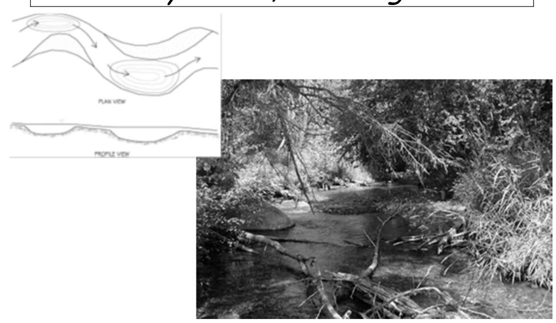
Plane Bed Stream Crossing

No real organized structure but has scattered boulders throughout

Polk Inlet
Alaska

Constructed margins (not bank in this case). **Note margin rock is too small.** Use embedded **stable** rock for banks and margins

Pool-riffle reach: Libby Creek, Washington.



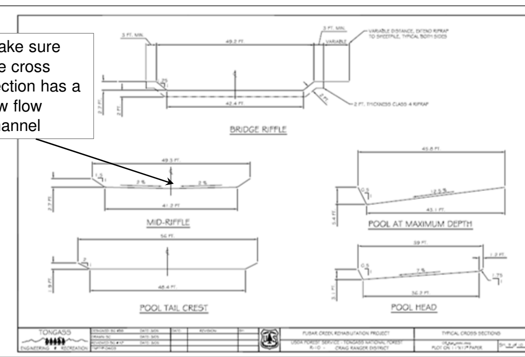
Pool-riffle reaches

- Have longitudinally undulating beds,
- A repeating sequence of pools and riffles regularly spaced at about 5-to 7-channel widths apart.
- May be sand to cobble-bedded streams. Large woody debris can alter the spacing.
- A flood plain is usually present

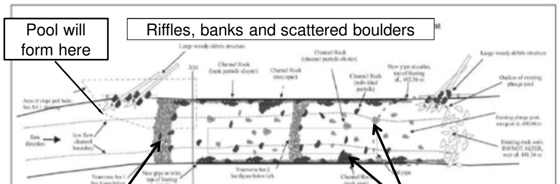
- Depending on the degree of armoring, bed mobilization may occur at or below bankfull. Armoring dependent
- Roughness along banks
- Bedforms can be ribs in riffles, particle clusters, and or large wood
- May need to construct an entire pool riffle sequence if the design profile is long enough.

Pool-riffle cross sections vary! If your design profile is long you may need a few kinds!

Make sure the cross section has a low flow channel



Pool Riffle Design



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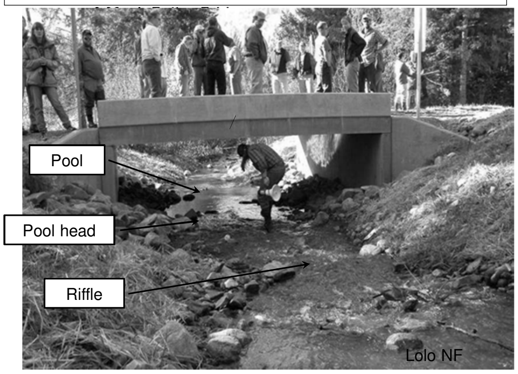
Pool Riffle Solutions



Dune-ripple reach: Coal Creek, Washington.

- Have low gradients (<0.5%) with sand and fine gravel beds.
- Transports sediment at virtually all flows
- Bedform change depending on water depth and velocity
- If sinuous, these streams also can have point bars.
- Easily effected by a head cut or loss of grade control

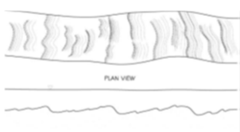
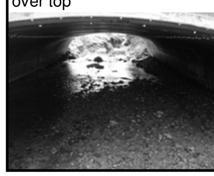


Photo: Kozmo Ken Bates.

Sandbed/Dune Ripple Design

- Minor increase in gradient can greatly affect sediment transport
- May want to add roughness at surface and below bed in pipe for material for bed topographic diversity, low flow channel maintenance and possible retention?
- Banks sized for permanence
- Even if abundant sediment supply, infill anyway to avoid headcuts

Armored beneath, fine gravel bed constructed over top



limited head cut when beaver dam failed

downstream channel

Rowdy Creek, Or.

Sand Bedded Solution in Vegetation Controlled Channel

Reference Reach

Sand Bedded Stream Simulation

Bedrock Reach

Bedrock Reaches

Bedrock channels exist
- where a bed of alluvial material has scoured off of bedrock
- where woody debris has been removed
- where a debris flow has scoured the channel to bedrock.
- or naturally occur

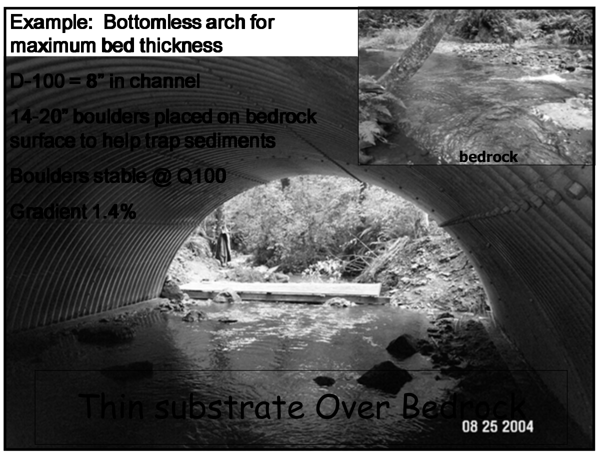
- Bedrock that does not show typical erosional features, such as fluting, longitudinal grooves, or potholes,
  - could indicate an alluvial veneer has recently washed away.
  - Recent channel incision due to channel realignment or straightening
- Large wood with sediment veneers and colluvium may be important grade features for enabling AOP.

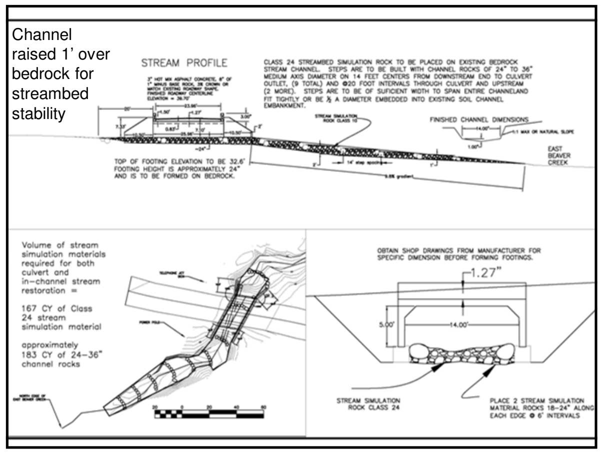
Bedrock Reach Design

Stream realignment & restoration may be appropriate.

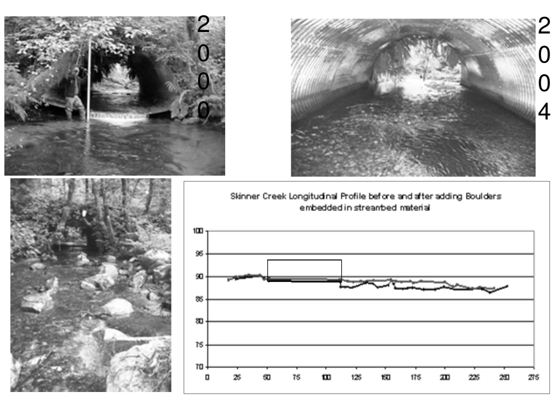
Stream simulation:

- Use large wood and boulders downstream to help trap sediment
- If it is determined the channel could be raised (long profile) a stream simulation channel can be built.
  - Base design on appropriate design for the gradient while considering bedrock key features.
- If not raised, use large immobile boulders to trap sediment in the structure and downstream.
  - Set boulders in bedrock depressions or anchoring in place with dowels, or shoot or impact hammer out keyway for boulder retention





Retrofit of bedrock channel / 1.2% Pool Riffle Channel



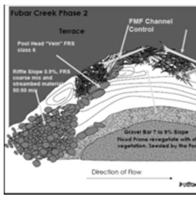
Cohesive Bed Reach

- No real experience with stream simulation in streams with cohesive beds Gradients usually very low and usually backwatered
- Beds consisting of primarily of fine sediments of high plasticity silt or clay
- Probably best to channel undisturbed by bridging bank to bank

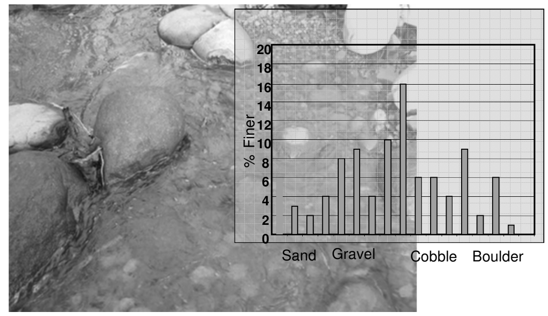
- If the channel is backwatered, a wide culvert might work by placing on the existing bed or embedding slightly and leaving it unfilled
- Foundations are an issue and a geotechnical investigation is required

Design Outside The Structure

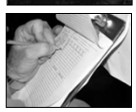
- Every thing you do inside the structure must be carried thru to the stream channel. Addition instream structures may be necessary transition to your tie points in banks and the stream bed.
- The same strategy used inside the structure is used outside except you can utilize wood and vegetation outside.
- Restoration may be required at some site. Those designs are much more involved.



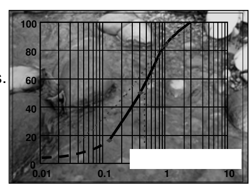
Stream Simulation Material is typically Well-graded (wide variety of sizes)



Bed Material Design – Alluvial



- New installations: use undisturbed channel (consider contraction)
- Replacements: use reference reach gradation.
  - Pebble count of reference channel for D_{95}, D_{84} and D_{50}
  - Include dense gradation based on D50 for smaller material and impermeability.
  - D_{30} and D_{10} reflect subsurface sizes
  - Fine-grained beds are special cases.
  - Compensate for stability of initial disturbed condition (add a couple of tenths in elevation depending on material).
  - Account for large roughness and forcing features.



Bed Material Design – Permeability

Larger particles sized directly from reference channel

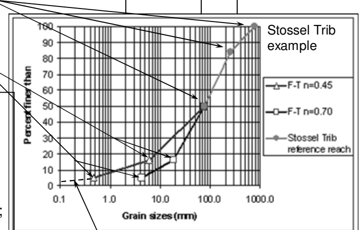
Small grains derived by Fuller-Thompson curve based on D_{50}

Fuller-Thompson

$$P = \left[\frac{d}{D_{100}}\right]^n$$

P = percent finer
d = diameter of particle
n = Fuller-Thompson density; varies 0.45 to 0.70

Simplify to:
$D30 = 0.6^{1/n} \times D50$
$D10 = 0.2^{1/n} \times D50$
$D5 = 0.1^{1/n} \times D50$



Verify 5% fines are included

Bed Material Example

W. Fork Stossel Cr.

	Ref. Reach	Strm Sim	Fuller-Thompson (assume n=0.45	Fuller-Thompson (assume n=0.7)	
D95	30”	30”	30”	30”	
D84	10”	10”	10”	10”	
D50	3”	3”	3”	3”	
D30			0.96”	1.45”	$= 0.60^{1/n} \times D50$
D10		5-10%	0.08”	0.30”	$= 0.20^{1/n} \times D50$
D5			0.02”	0.11”	$= 0.10^{1/n} \times D50$
Fines					

Sands and finer   Which is:

Base selection of Fuller Thompson N value on visually estimated sub surface sediment distribution. The goal is a dense mixture that minimizes permeability (void spaces) Ensure 5% of the mix contains fines (sand/silt/clay) if the D5 is greater than 2mm adjust the D5 to include the fine component in the specifications

Fuller Thompson Equation

Choose a range that gives the same as observed in the subsurface sediment

FINE → COARSE

n	0.45	0.5	0.55	0.6	0.65	0.7
D-50	3.00	3.00	3.00	3.00	3.00	3.00
D-30	0.96	1.08	1.19	1.28	1.37	1.45
D-10	0.08	0.12	0.16	0.21	0.25	0.30
D-5	0.02	0.03	0.05	0.06	0.09	0.11

Bed material example design and spec

W Fk Stossel Cr

	Reference	Design
D95	30”	30”
D84	10”	10”
D50	3”	3”
D30		1.45
D10		0.3”
D5	sand	0.11”
Fines		5-10%
Colluvium, debris	Spanning 6-12” debris at 50’ spacing	24” rock scattered at 15’ oc throughout
Banklines	Bankline root structure protrudes 3’ at 25’ spacing	36” bankline rock at 25’ spacing or continuous each bank

D5 greater than 2mm add additional fines

Bed material in channels with small grain material

- Lower risk with bed higher mobility
- Less practical to design detailed bed material
- When D84 < 20 mm
  - Use natural bed material
  - Select borrow
    - Does bed satisfy objective?
  - If sand bedded can allow natural filling but ensure
    - Headcut risk is understood
    - Consider volume of culvert fill and its effect on the stream (big structures require a lot of infill)

Example spec

Select Borrow	
Sieve size	% by weight
75 mm	100
25 mm	70 – 100
4.75 mm	30 – 70
150 um	0 - 15

KEY PIECE DESIGN PROCEDURE

Procedure:

1) Determine the d95, d84, d50, and d16 percentile for each axis of the particles (Hint: Done by using percentile function in Excel for the column of data).

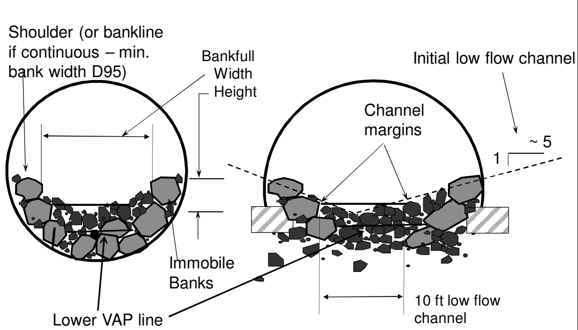
2) Determine the average cubic dimension of the different percentiles.

3) Determine the cubic dimension range of the key pieces, particle shape, and the average ratio of the long axis and intermediate axis particles.

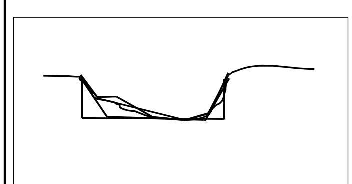
PERCENTILE FORMULA=+PERCENTILE(B21:B30,0.95)

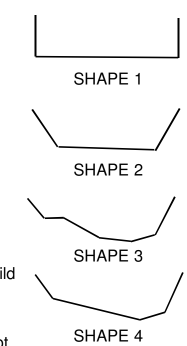
AVE. CUBIC DIMENSION = (B33*C33*D33)^(1/3)

Stream Simulation Bed Channel Cross-section



Fitting Cross Section Shapes





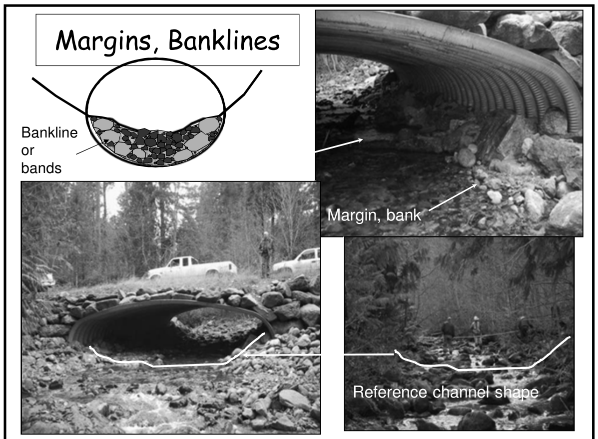
✓Keep it similar to the reference reach

✓Avoid overly complex section

✓Everything works on paper but can you build the cross section in the field?

✓Constructability is based on bed material sizes….ie boulders and large cobbles are not easily made into complex cross section shapes

Margins, Banklines



Design of Stream Banks / Margins

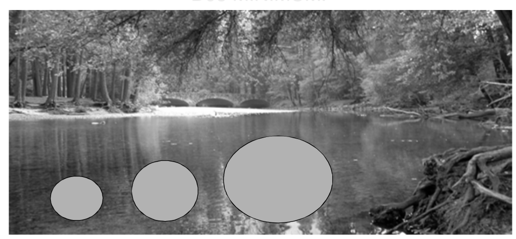
- Banks have shelves (tops of banks like floodplains) and margins are continous or discontinous roughness along the margin.
- Both are designed for permanence using stable rock D95+
- Minimum bank width D95 each side, if rock is small may need 2 or more deep or use a larger single piece) keep in mind terrestrial passage needs
- Margins are composed of large rock and coarse bed particles and stream sim bed mix
- Margins may be lower lying to almost bank like.
- Both can provide terrestrial passage and provide hydraulic diversity

Without banks, bed is either overwide and featureless or flow concentrates toward the side and can scour footings, concentrate flow and create a barrier on steeper streams

Shallow flow margins are important for some organism to move upstream

How big should bank boulders be?

SIZE THEM TO LAST THRU THE Q100
D95 MINIMUM.



Exercise 6b
Prelim Width, Bed & Bank Design

- **Structure width, design bed mix, key pieces, and bed/bank features**

>>X10